**Attachment A**

**Methodology for Determining Child Use Area Boundary**

(From: Glass, Gregory L. 2002b. Sampling Design for Tacoma Smelter Plume Site; Soil Sampling and Analysis at Child Use Areas in King County and Pierce County, Washington. November.)

The Pierce County Footprint Study, completed in November 2002, provides soil arsenic results for 194 locations: 105 disturbed locations (residential property sampling) and 89 undisturbed locations. A Child-Use Areas Study Zone for Pierce County is defined to include those portions of Pierce County where soil arsenic concentrations could exceed 100 ppm. The data from the Footprint Study (supplemented by a few additional values from earlier studies, as described below) were evaluated, using the same methodology already described for the King County Mainland (see Attachment B- Glass, 2002b), to estimate bounding curves for each of 13 wind sectors included in the Pierce County Footprint Study. Each bounding curve equation can be used to calculate an estimated maximal distance, for one wind sector, at which soil arsenic concentrations at or above 100 ppm are likely to occur. The Child-Use Areas Study Zone is defined based on this set of maximal distances (across wind sectors) for 100 ppm soil arsenic. The bounding curve equations will also be used to assign maximum likely values to candidate child-use areas in Pierce County as part of a scoring and prioritization system (see Attachment A).

The evaluations for defining a Pierce County Child-Use Areas Study Zone were carried out using the same basic methodology used for King County. The soil arsenic results for the 194 sampling locations from the Footprint Study were the primary data used. Two types of supplemental data were reviewed and selectively used: 1) for the East-Northeast and East wind sectors, data from the King County Mainland study were added to the Pierce County Footprint Study results (providing an expanded view of spatial gradients for those wind sectors), and 2) historic studies from Pierce County were reviewed and a few results added to the evaluations where they resulted in an elevated bounding curve. There were also two new considerations compared to the King County child-use areas study zone evaluations: 1) the possibility that soil sampling results from areas extending well beyond smelter impacts could artificially raise the bounding curve, and 2) the possibility that a few results close to the former smelter could reflect contamination from smelter sources other than tall stack emissions (e.g., fugitive emissions). These methodology issues are briefly discussed below, followed by a summary of the results for each wind sector.

In brief, the bounding curve equations were developed as follows: 1) a database of maximum soil arsenic results by sampling location, together with distance and direction values from the tall stack, was compiled; 2) that database was partitioned according to wind sector (each 22.5 degrees wide, centered on one of 16 compass directions such as South-Southwest); 3) the maximum soil arsenic values were plotted

(using log-scaled concentrations) versus distance for each wind sector, coded to distinguish undisturbed from disturbed sampling locations; 4) historic data and King County results were added to the scatterplots as appropriate; 5) a bounding line was drawn for each wind sector scatterplot; and 6) the intercept and slope of the bounding line were measured to establish the bounding line equation. The resulting bounding curve equations have the form of a decay function with the general equation

$$\text{maximum arsenic} = A\ 10^{(\text{slope}*D)}$$

where A is a constant and D is the distance (in miles) from the stack (see Attachment B for details).

Many of the Pierce County wind sector scatterplots included only a relatively small number of data points. In some cases, multiple options for how to draw a bounding line presented themselves. Judgment was used to select from among the options in such cases, considering which bounding lines gave the best overall fit to the available wind sector data as well as the spatial pattern for regional transport of tall stack emissions as reflected by the annual wind rose.

The chosen form for the decay equation asymptotes to a maximum arsenic value of zero; that is, as the distances increase, the calculated maximum arsenic concentration becomes closer and closer to zero. The regional background value for soil arsenic, in areas unaffected by smelter emissions, is of course somewhat greater than zero. Where sampling results include regions extending well beyond the area of smelter impacts - that is, where many background locations are included - fitting a bounding curve to a non-zero (background) value for one of the most distant sampling locations will artificially raise the bounding curve. The more distant the sampling locations included, the greater will be the degree of bias in the bounding curve. The Pierce County Footprint Study, by design, included areas (e.g. to the northwest) where smelter impacts were judged unlikely to be significant based on the annual wind rose patterns. (The King County Mainland study, by contrast, does not similarly extend into background regions). For several Pierce County wind sectors, the data appeared to represent sampling into the background region, beyond significant smelter impacts. In those cases, bounding curves were drawn using a sampling location judged to represent the approximate beginning of a background region, to avoid upward bias in the bounding curve.

The Pierce County Footprint Study includes sampling locations much closer to the smelter than either the Vashon-Maury Island or King County Mainland studies. Locations close to the smelter are more affected by low-level fugitive releases from smelter operations, and other accidental releases (e.g., from stack fires), than by typical tall stack releases. The distance at which tall stack releases dominate soil contamination impacts has not been accurately defined. A data set in which both regional tall stack effects and localized fugitive emissions effects are present would have a more complicated bounding curve, reflecting two different decay functions. Fitting a single decay curve to a data set containing both soil impact processes could bias the bounding curve and the estimated maximal distance to a 100 ppm soil arsenic concentration.

(Largely for that reason, the results from detailed property-by-property sampling within the Ruston/North Tacoma Superfund site and other historic soils data within about 1 mile of the smelter have not been considered for defining a child-use areas study zone). One high-outlier maximum arsenic result, from a sampling location close to the Ruston/North Tacoma Superfund boundary, was of particular concern with respect to the possibility of introducing bias (see the discussion of Southwest wind sector results below). After considering all results for that wind sector, a judgment was made to keep the high-outlier result in the analysis. Some even higher soil arsenic results from historic studies at locations a little closer to the smelter were not included in the evaluations (see the discussion of South-Southwest wind sector results below).

Soil arsenic data from various historic studies were considered as part of the study zone evaluations. The Pierce County Footprint Study represents the most extensive and current sampling of Pierce County soils outside of the Ruston/North Tacoma Superfund site. However, historic data provide additional valid results for defining the overall spatial patterns of soil arsenic contamination. In some cases, the sampling densities in historic studies are much greater than Footprint Study sampling densities in the same areas. Higher sampling densities are more likely to include significantly higher values (from among locally varying values). Historic studies have also included undisturbed sampling locations that were not, or could not be, resampled in the Footprint Study. Soil arsenic concentrations are not expected to have decreased naturally (e.g., by leaching or volatilization) in the years since sampling in historic studies; the reported results should therefore be representative of current spatial distributions. The collected historic studies with soil arsenic data for Pierce County were reviewed; the references list identifies those of most interest for the child-use areas study zone evaluations. In those few cases where historic data resulted in an elevated boundary curve, the sources for historic data are given in the discussions of wind sector results below.

Where appropriate, the results from both Pierce County and King County studies were combined to provide the most extensive data sets for evaluating concentration-by-distance patterns (East-Northeast and East wind sectors).

**Results**. The results of the evaluations for each wind sector are briefly described below. The number of Footprint Study sampling locations (out of the total of 194) is given after each heading (n = number of locations by wind sector), as well as the range of directions (bearing degrees clockwise from due north = 0 degrees) for each wind sector. In some cases, additional information is provided summarizing the results of alternate analyses.

North-Northwest. (n = 1) The North-Northwest wind sector (326.25 to 348.75 degrees) includes only a single undisturbed sampling location in the northern Gig Harbor peninsula, near the Kitsap County boundary line. The maximum arsenic concentration there is 17 ppm. Data are insufficient to estimate a bounding curve for this wind sector. (In this wind direction, no populated areas occur within almost four miles of the smelter tall stack). South Vashon Island sampling locations just east of the northern Gig Harbor

peninsula, in the North wind sector, were found to have maximum soil arsenic levels exceeding 100 ppm. The annual wind rose (North 26th and Pearl Streets, Tacoma, WA) shows substantially less frequent winds to the North-Northwest than to the North (and somewhat more frequent winds than to the Northwest*).(Note: this wind sector was later estimated to be 4.1 miles. See Attachment A-1 for explanation).*

Northwest. (n = 6) The Northwest wind sector (303.75 to 326.25 degrees) includes only undisturbed sampling locations. The highest soil arsenic result of 64.5 ppm occurs at the closest sampling location, along the Gig Harbor peninsula shoreline at almost four miles from the smelter stack. Without considering soil background issues, the bounding line would be defined by a 4.43 ppm arsenic result at a sampling location almost 13 miles from the smelter (with an equation of max arsenic = $210 \times 10^{-0.131 \text{ Distance}}$). However, based on the annual wind rose and pattern of soil results, the selected bounding curve was based on the next most-constraining data point (10.3 ppm at almost 9.5 miles) to reduce the possible bias introduced by having results extending into the background region. The equation for the bounding curve is therefore

$$\text{max arsenic} = 240 \times 10^{-0.145 \text{ Distance}}$$

with a calculated distance to 100 ppm of approximately 2.6 miles.

West-Northwest. (n = 11) The West-Northwest wind sector (281.25 to 303.75 degrees) includes only undisturbed sampling locations extending over 15 miles to the far northwest corner of Pierce County (near the Mason and Kitsap County lines). The highest soil arsenic result of 60.7 ppm occurs at a distance of almost four miles from the smelter stack. An adjustment in drawing the bounding line to account for sampling into the background region makes a greater difference here than in the Northwest wind sector. Excluding likely background region samples results in a greater calculated distance to 100 ppm maximum soil arsenic. The unconstrained bounding line (determined by the maximum result of 60.7 ppm and a 12.8 ppm value at almost 14 miles), with the estimated equation max arsenic = $115 \times 10^{-0.070 \text{ Distance}}$, has a distance to 100 ppm of only 0.9 miles. The selected bounding curve, with four sampling results nearly on the line, has an equation of

$$\text{max arsenic} = 320 \times 10^{-0.184 \text{ Distance}}$$

and a calculated distance to 100 ppm of approximately 2.7 miles. The slope for the chosen boundary curve is much more consistent with the annual wind rose (which shows a very low frequency in this direction) and the overall spatial pattern of soil contamination.

West. (n = 15) The West wind sector (258.75 to 281.25 degrees) includes only undisturbed sampling locations extending to almost 15 miles from the smelter (to the western side of the Key Peninsula). The highest soil arsenic result of 171 ppm occurs at the closest sampling location, along the eastern shore of the Gig Harbor peninsula. As is true of the Northwest and West-Northwest wind sectors, the annual wind rose shows a

very low wind frequency for the West direction. An adjustment in drawing the bounding line to account for sampling into the background region makes a relatively small difference in the bounding curve. The unconstrained bounding line (determined by the highest result and a 7.18 ppm result at the most distant sampling location), with the estimated equation max arsenic = $300 \times 10^{-0.109 \text{ Distance}}$, has a distance to 100 ppm of approximately 4.4 miles. The selected bounding curve, which provides a better fit to the results within 8 miles of the smelter, has an equation of

$$\text{max arsenic} = 360 \times 10^{-0.143 \text{ Distance}}$$

and a calculated distance to 100 ppm of approximately 3.9 miles. One historic value from a sampling location on the western end of Fox Island (Crecelius et al. 1974) falls almost exactly on the selected bounding line.

West-Southwest. (n = 22) The West-Southwest wind sector (236.25 to 258.75 degrees) includes one disturbed and 21 undisturbed locations, extending about 15 miles to the southern Key Peninsula. The undisturbed sampling location, less than one mile from the smelter stack, is closest to the smelter and has the highest arsenic result of 142 ppm. The bounding line, however, is determined by a value of 80.8 ppm on central Fox Island and an 11.8 ppm result from the Key Peninsula. A value of 31.4 ppm on McNeil Island is also nearly on this bounding line; thus, in contrast to the previous three wind sectors, an adjustment for sampling into the background region is not warranted. The bounding curve has an equation of

$$\text{max arsenic} = 380 \times 10^{-0.101 \text{ Distance}}$$

and a calculated distance to 100 ppm of approximately 5.7 miles.

Southwest. (n = 19) The Southwest wind sector (213.75 to 236.25 degrees) has three disturbed and 16 undisturbed sampling locations, extending over 14 miles to include portions of Fox and McNeil Islands and all of Anderson Island. The highest arsenic result of 1,050 ppm for this wind sector is the highest value for the entire Footprint Study and statistically is a high-outlier; the next highest value of 475 ppm (in the South-Southwest wind sector) is less than half as large. The third highest maximum arsenic result from the Footprint Study, 440 ppm, also occurs in this Southwest wind sector at a disturbed sampling location.

The 1,050 ppm result is from an undisturbed location about 1.3 miles from the smelter stack. One likely reason that the 1,050 ppm result appears to be a high outlier is that it represents one of the only undisturbed locations sampled in areas close to the former smelter; comparisons to other results therefore involve the difference between disturbed and undisturbed soil conditions. Including or excluding the 1,050 ppm result has only a small effect on the calculated distance to 100 ppm; the main difference between the bounding curves is in the arsenic concentrations calculated for locations within about 6 miles of the smelter. A judgment was made that the 1,050 ppm result should be retained for analysis. The bounding curve is then determined by that highest

value and two results from Anderson Island (62.5 ppm and 43.1 ppm) and has the equation

$$\text{max arsenic} = 1{,}450 \times 10^{-0.106\ \text{Distance}}$$

and a calculated distance to 100 ppm of approximately 11.0 miles. Seven sampling locations in this wind sector, at distances up to 7 miles from the smelter, had actual maximum arsenic concentrations above 100 ppm. The Footprint Study results on eastern Fox Island, up to 182 ppm, confirmed the early result in Crecelius et al. (1974) of 166 ppm in that area.

South-Southwest. (n = 43) The South-Southwest wind sector (191.25 to 213.75 degrees) includes parts of the highly developed Pierce County mainland in Tacoma and University Place. Of the 43 sampling locations in this wind sector, the majority - 27 - are disturbed (residential) locations. Examination of the scatterplot of maximum arsenic results versus distance confirms that at similar distances the results from undisturbed locations are higher than those from disturbed locations. This supports the general approach of using undisturbed sampling results to estimate upper bounds on possible soil arsenic concentrations at disturbed properties.

The highest arsenic value for this wind sector is 475 ppm from an undisturbed location a little over two miles from the smelter stack. Nine sampling locations (four undisturbed, five disturbed) have maximum arsenic results over 100 ppm, at distances up to almost seven miles from the smelter. Values above 90 ppm occur to distances of about 15 miles. Annual wind roses show this wind direction to have the highest frequency for Pierce County.

Some of the undisturbed areas included in the Tacoma Water area background study in University Place (City of Tacoma and Glass 1999) were resampled in the Footprint Study. The original area background investigation, however, sampled more undisturbed locations and had a higher local density of sampling than the Footprint Study. A review of the Tacoma Water data resulted in adding maximum arsenic values for seven locations to the scatterplot. The addition of these data resulted in a very modest elevation of the bounding line, with the determining result being a maximum arsenic value of 281 ppm from the Tacoma Water study at a distance of about six and a half miles from the smelter. (The highest value from resampling this location in the Footprint Study was 204 ppm). The maximum value for this wind sector, 475 ppm, and a 91.6 ppm value from DuPont over 15 miles from the smelter would determine a very nearly identical bounding line. The equation for the bounding curve using the Tacoma Water results is

$$\text{max arsenic} = 650 \times 10^{-0.055\ \text{Distance}}$$

and a calculated distance to 100 ppm of approximately 14.8 miles.

Historic soil sampling results from several vacant lots in this wind sector, at distances of a little more than a mile from the smelter, show very high arsenic concentrations (see ASARCO 1978). Intensive sampling of these lots was initiated by a proposal to build low-cost housing (Mayer Built Homes project). They are located very close to the Footprint Study sampling location with 1,050 ppm maximum arsenic (discussed under Southwest wind sector above). Three sampled lots had maximum arsenic concentrations of 3,060 ppm, 2,160 ppm, and 2,040 ppm. These highest results were added to the scatterplot and a bounding equation, determined by the 3,060 ppm value and the 91.6 ppm result at over 15 miles from the smelter, was estimated. This alternate equation (max arsenic = $3{,}950 \times 10^{-0.109\ \text{Distance}}$) would have almost no effect on the calculated distance to 100 ppm (14.7 miles) but would produce much higher calculated maximum arsenic concentrations. For example, at 4 miles the calculated value would be about 1,450 ppm versus about 390 ppm for the selected bounding curve. Considering the poor fit of the alternate bounding curve to available data for this wind sector, and the possibility that the high soil arsenic values from the historic sampling reflect a different process for smelter impacts, the historic data were not used to estimate a bounding curve.

South. (n = 30) The South wind sector (168.75 to 191.25 degrees) includes only 2 undisturbed sampling locations; the remaining 28 locations are disturbed (residential). Sampling locations include Tacoma, Fircrest, and Lakewood areas to distances of almost 10 miles from the smelter. The lack of undisturbed sampling locations for this wind sector, and the limited number of disturbed locations sampled overall, means that the estimated bounding curve may be biased low to a degree greater than for other wind sectors (e.g., South-Southwest).

The highest soil arsenic result for this wind sector is 233 ppm, occurring for a disturbed property about one mile from the smelter stack. The bounding curve is determined by that result and a value of 30 ppm at a Lakewood sampling location at a distance approaching 10 miles. The bounding curve equation is

$$\text{max arsenic} = 300 \times 10^{-0.103\ \text{Distance}}$$

giving a calculated distance to 100 ppm of approximately 4.6 miles.

South-Southeast. (n = 21) The South-Southeast wind sector (146.25 to 168.75 degrees) includes only disturbed sampling locations. The estimated bounding curve may therefore be biased low, as in the case of the South wind sector. The highest soil arsenic result is 140 ppm from a sampling location about one and a half miles from the smelter. The bounding curve is determined by that result and a value of 10.3 ppm at the most distant sampling location about 5 miles from the smelter (near the Highway 16 and I-5 junction). It is possible that the Footprint Study extends marginally into a background region in this wind sector; the wind rose shows a low frequency of winds in this direction. Given the overall trend of the results by distance, however, any adjustments for background sampling would be of little consequence. Therefore, all of the data were included in the bounding curve evaluation. The bounding curve equation is

$$\text{max arsenic} = 440 \times 10^{-0.326\ \text{Distance}}$$

with a calculated distance to 100 ppm of approximately 2.0 miles.

Southeast. (n = 15) The Southeast wind sector (123.75 to 146.25 degrees) includes only disturbed sampling locations. The estimated bounding curve may therefore be biased low. A review of historic studies determined that one result from the Exposure Pathways Study (Polissar et al. 1987), also from a residential property, would elevate the bounding line. That result was therefore added to the scatterplot. The historic sampling result of 58 ppm at a distance of about one and a half miles from the smelter is the highest arsenic result for the Southeast wind sector. That highest value and a value of 20.7 ppm from the most distant sampling location, in the Hilltop area almost five miles from the smelter, determined the bounding line. The bounding curve equation is

$$\text{max arsenic} = 90 \times 10^{-0.130\ \text{Distance}}$$

which gives a calculated distance to 100 ppm of less than 0 miles. (Since sampling results from the Ruston/North Tacoma Superfund site have been excluded from these evaluations, a default of using the limit of that area in this wind sector for defining a child-use area study zone could be considered).

East-Southeast. (n = 3) The East-Southeast wind sector (101.25 to 123.75 degrees) includes only 3 disturbed sampling locations at distances of about 7 to 8 miles near Fife. These data are insufficient to estimate a bounding curve. However, since no populated areas occur within about five miles of the smelter in this direction, and the highest soil arsenic result from the Footprint Study is only 20.1 ppm, the consequences for defining a study zone are minimal.

East. (n = 6) The East wind sector (78.75 to 101.25 degrees) includes only disturbed sampling locations from the Footprint Study, extending to about 6 miles in Northeast Tacoma. An additional 10 undisturbed sampling locations have results from the King County Mainland study. Both sets of results were included in the initial data scatterplot. A review of historic studies determined that results from two previous investigations, both at relatively undisturbed sampling locations, would elevate the bounding line. An early study by Crecelius et al. (1974) included sampling at a park near Browns Point that could not be resampled in the Footprint Study. The soil arsenic value of 244 ppm, at a distance of about 3 miles, is the highest value for the East wind sector.[1] An academic study of forest soils impacted by smelter emissions (see Dempsey 1991) reported a soil arsenic value of about 110 ppm at a distance of about five miles in this

[1]A reported soil arsenic value of over 900 ppm, at a Northeast Tacoma sampling location, from the EPA Urban Soil Monitoring Program appears highly anomalous and is not considered further. It may represent a local application of arsenical herbicides or pesticides.

wind sector (from among a set of sampled locations in the region). These historic data were added to the scatterplot. The bounding line is determined by the Crecelius et al. result of 244 ppm near Browns Point and a 41 ppm result from the King County Mainland Study at a distance of almost twelve miles. The Dempsey result approaches this bounding line. The bounding curve is identical to the one used for the King County study zone definition (see Attachment B), with an equation of

$$\text{max arsenic} = 450 \times 10^{-0.090\ \text{Distance}}$$

and a calculated distance to 100 ppm of approximately 7.3 miles.

East-Northeast. (n = 2) The East-Northeast wind sector (56.25 to 78.75 degrees) includes one disturbed and one undisturbed sampling location. Only a small area of Pierce County near Browns Point in Northeast Tacoma occurs within this wind sector. The King County Mainland Study provides another 27 results for the East-Northeast wind sector, which according to the annual wind rose is one of the dominant downwind directions for smelter emissions. The King County results include values over 100 ppm to distances of more than 11 miles from the smelter. The higher of the two Pierce County results is only 44.9 ppm at a distance of about 4 miles. A review of historic studies identified a soil arsenic value of 100 ppm in the Dempsey (1991) forest soils study, at a distance of about 6 miles. The low density of results within Pierce County for this direction makes evaluations difficult. Combining the Pierce County and King County results, the bounding line is entirely determined by King County results (180 ppm at a distance of about 11 miles and 51 ppm at a distance of about 19 miles). The equation is therefore identical to the one used for King County for the East-Northeast wind sector (see Attachment B), with an equation of

$$\text{max arsenic} = 1125 \times 10^{-0.071\ \text{Distance}}$$

and a calculated distance to 100 ppm of approximately 14.8 miles.

Inspection of the spatial pattern for the King County results suggests that the northern part of this wind sector has higher values than the southern part. The Pierce County areas within the East-Northeast wind sector fall within the southern half. The trend in annual wind rose frequencies by direction also seems consistent with more frequent winds in the northern part of this wind sector. An alternative analysis using only the Pierce County Footprint Study results, the historic Dempsey result, and those King County Mainland results in the sub-sector defined by Pierce County lands in the East-Northeast direction was carried out. The bounding line is determined by King County results of 62 ppm at about 11 miles and 30 ppm at a distance approaching 17 miles; the Dempsey result of 100 ppm approaches this bounding line, as do several other King County results. The alternative bounding curve equation is

$$\text{max arsenic} = 250 \times 10\ -0.054\ \text{Distance}$$

which gives a calculated distance to 100 ppm of 7.4 miles, half the previous distance. This alternative evaluation would not alter the conclusion that all of the small Pierce County area in the East-Northeast wind sector should be included in the child-use areas study zone. For consistency in approach, the bounding curve matching the King County analysis may be used.

The set of bounding curves for Pierce County shows a strong concordance with a conceptual model for smelter tall stack emissions as influenced by annual wind rose frequencies. The calculated distances to 100 ppm soil arsenic correlate well with wind frequencies. The slopes by wind sector also show the expected pattern of faster decreases with distance when wind frequencies are low versus when they are high. Unlike the King County evaluations, which were based only on sampling results for undisturbed (forested) locations, the Pierce County evaluations included both disturbed and undisturbed locations. For some wind sectors, only disturbed location results are available. The lack of results from undisturbed locations in some wind sectors may bias the estimated bounding curves low. The number of results by wind sector in Pierce County is also much lower than for the primary downwind directions (North-Northeast and Northeast) in King County. That may also contribute to a somewhat larger degree of low bias for the Pierce County results. Nevertheless, the set of bounding curves appears to provide a reasonable basis for defining a child-use areas study zone for Pierce County and for prioritizing among candidate child-use areas for sampling.

East-Southeast. (n = 3) The East-Southeast wind sector (101.25 to 123.75 degrees) includes only 3 disturbed sampling locations at distances of about 7 to 8 miles near Fife. These data are insufficient to estimate a bounding curve. However, since no populated areas occur within about five miles of the smelter in this direction, and the highest soil arsenic result from the Footprint Study is only 20.1 ppm, the consequences for defining a study zone are minimal.

East. (n = 6) The East wind sector (78.75 to 101.25 degrees) includes only disturbed sampling locations from the Footprint Study, extending to about 6 miles in Northeast Tacoma. An additional 10 undisturbed sampling locations have results from the King County Mainland study. Both sets of results were included in the initial data scatterplot. A review of historic studies determined that results from two previous investigations, both at relatively undisturbed sampling locations, would elevate the bounding line. An early study by Crecelius et al. (1974) included sampling at a park near Browns Point that could not be resampled in the Footprint Study. The soil arsenic value of 244 ppm, at a distance of about 3 miles, is the highest value for the East wind sector.[2] An academic study of forest soils impacted by smelter emissions (see Dempsey 1991) reported a soil arsenic value of about 110 ppm at a distance of about five miles in this

[2]A reported soil arsenic value of over 900 ppm, at a Northeast Tacoma sampling location, from the EPA Urban Soil Monitoring Program appears highly anomalous and is not considered further. It may represent a local application of arsenical herbicides or pesticides.

wind sector (from among a set of sampled locations in the region). These historic data were added to the scatterplot. The bounding line is determined by the Crecelius et al. result of 244 ppm near Browns Point and a 41 ppm result from the King County Mainland Study at a distance of almost twelve miles. The Dempsey result approaches this bounding line. The bounding curve is identical to the one used for the King County study zone definition (see Attachment B), with an equation of

$$\text{max arsenic} = 450 \times 10^{-0.090\ \text{Distance}}$$

and a calculated distance to 100 ppm of approximately 7.3 miles.

East-Northeast. (n = 2) The East-Northeast wind sector (56.25 to 78.75 degrees) includes one disturbed and one undisturbed sampling location. Only a small area of Pierce County near Browns Point in Northeast Tacoma occurs within this wind sector. The King County Mainland Study provides another 27 results for the East-Northeast wind sector, which according to the annual wind rose is one of the dominant downwind directions for smelter emissions. The King County results include values over 100 ppm to distances of more than 11 miles from the smelter. The higher of the two Pierce County results is only 44.9 ppm at a distance of about 4 miles. A review of historic studies identified a soil arsenic value of 100 ppm in the Dempsey (1991) forest soils study, at a distance of about 6 miles. The low density of results within Pierce County for this direction makes evaluations difficult. Combining the Pierce County and King County results, the bounding line is entirely determined by King County results (180 ppm at a distance of about 11 miles and 51 ppm at a distance of about 19 miles). The equation is therefore identical to the one used for King County for the East-Northeast wind sector (see Attachment B), with an equation of

$$\text{max arsenic} = 1125 \times 10^{-0.071\ \text{Distance}}$$

and a calculated distance to 100 ppm of approximately 14.8 miles.

Inspection of the spatial pattern for the King County results suggests that the northern part of this wind sector has higher values than the southern part. The Pierce County areas within the East-Northeast wind sector fall within the southern half. The trend in annual wind rose frequencies by direction also seems consistent with more frequent winds in the northern part of this wind sector. An alternative analysis using only the Pierce County Footprint Study results, the historic Dempsey result, and those King County Mainland results in the sub-sector defined by Pierce County lands in the East-Northeast direction was carried out. The bounding line is determined by King County results of 62 ppm at about 11 miles and 30 ppm at a distance approaching 17 miles; the Dempsey result of 100 ppm approaches this bounding line, as do several other King County results. The alternative bounding curve equation is

$$\text{max arsenic} = 250 \times 10\ -0.054\ \text{Distance}$$

which gives a calculated distance to 100 ppm of 7.4 miles, half the previous distance. This alternative evaluation would not alter the conclusion that all of the small Pierce County area in the East-Northeast wind sector should be included in the child-use areas study zone. For consistency in approach, the bounding curve matching the King County analysis may be used.

The set of bounding curves for Pierce County shows a strong concordance with a conceptual model for smelter tall stack emissions as influenced by annual wind rose frequencies. The calculated distances to 100 ppm soil arsenic correlate well with wind frequencies. The slopes by wind sector also show the expected pattern of faster decreases with distance when wind frequencies are low versus when they are high. Unlike the King County evaluations, which were based only on sampling results for undisturbed (forested) locations, the Pierce County evaluations included both disturbed and undisturbed locations. For some wind sectors, only disturbed location results are available. The lack of results from undisturbed locations in some wind sectors may bias the estimated bounding curves low. The number of results by wind sector in Pierce County is also much lower than for the primary downwind directions (North-Northeast and Northeast) in King County. That may also contribute to a somewhat larger degree of low bias for the Pierce County results. Nevertheless, the set of bounding curves appears to provide a reasonable basis for defining a child-use areas study zone for Pierce County and for prioritizing among candidate child-use areas for sampling.

## Attachment A-1: Explanation of Child Use Area Boundary Determination in North-Northwest Wind Direction

-----Original Message-----
**From:** Greg Glass [mailto:glassec@attbi.com]
**Sent:** Tuesday, December 17, 2002 1:16 PM
**To:** Abbett, Marian L.
**Subject:** NNW Wind Sector

Marian,

Here is the procedure leading to an estimate of 4.1 miles for the distance to 100 ppm maximum soil arsenic for the NNW wind sector of the Tacoma Smelter Plume site.

Only one location in the NNW wind sector was sampled. That location (#710) is near the western limit of the NNW wind sector, Thus our data are insufficient to derive a bounding curve, as was done for other wind sectors.

Annual wind roses from PSAPCA are available for many years. There is great similarity in the frequencies by direction from one year to another. The wind frequencies for the NW, NNW, and N wind sectors are approximately 1 to 1.5 percent, 3 percent, and 6 to 7.5 percent, respectively. Thus the frequency for the NNW wind sector is intermediate between the frequencies for the N and NW wind sectors. Our regional spatial patterns for soil contaminant concentrations and the conceptual model for transport and deposition of tall stack emissions both indicate that the magnitude and spatial extent of soil arsenic concentrations should generally follow wind frequencies.

There are 88 sampling locations with soil arsenic data for the N wind sector, from the initial VMI study. While those 88 results were analyzed as one data set to develop a bounding curve for the N wind sector, inspection of the data and consideration of the 360-degree wind field pattern suggest that there are differences within the wind sector; the western half of the N wind sector likely has less contamination than the eastern half. (Refer to the discussions in Attachment C for a similar evaluation for another wind sector).

I produced a new scatterplot for the western half of the N wind sector (all data from location with direction from the tall stack of less than or equal to 0 degrees). Out of the 88 total locations for the N sector, 15 fall in the western half. I repeated the evaluation process previously applied to estimate a bounding equation for only those data. As expected the slope for the bounding curve was steeper than for all 88 data points for the N sector. The estimated distance to 100 ppm maximum soil arsenic using the 15 selected data points was 7.5 miles. (NOTE: a value of 260 ppm at a little less than 5 miles appears as a modest high-outlier value on the scatterplot. I kept that result in for the bounding curve evaluation. Without it, the distance to 100 ppm would be reduced to 5.6 miles).

The results for distances to 100 ppm for the NW wind sector and the western half of the N wind sector were used along with typical annual wind frequencies of 1.5% (NW), 3% (NNW), and 6.5% (N) to calculate a distance D for the NNW wind sector.

Thus,

(D-2.6 miles)/(7.5 miles-2.6 miles) = (3%-1.5%)/(6.5%-1.5%)

giving

D = 2.6 miles + (4.9)(0.3) = 4.07 miles, rounded to 4.1 miles

I recommend in the absence of sufficient sampling data for the NNW sector we use this distance of 4.1 miles as an estimate for mapping purposes.

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